

TITLE OF THE INVENTION:
SYNTHESIS OF PENTAFLUOROSULFURANYL SUBSTITUTED ALKANES

BACKGROUND OF THE INVENTION

[0001] The development of synthetic methodologies for the introduction of sulfurpentafluoride or pentafluorosulfuranyl groups ("SF₅") into organic compounds has been pursued with a considerable degree of interest. The SF₅ groups impart unique properties to these organic compounds that include, *inter alia*, low surface energy, high chemical resistance, high thermal stability, high electronegativity, hydrophobicity, and high dielectric constant. The high electronegativity value of the SF₅ group, 3.62 on the Pauling scale, and its greater electron withdrawing ability makes it an attractive alternative for the trifluoromethyl group ("CF₃") found in many commercial products.

[0002] Organic compositions containing SF₅ have been used in a variety of applications. For example, pentafluorosulfuranyl fluoroaliphatic compositions have been used as surfactants, mono and bis (pentafluorosulfur)-substituted diacetylenes have been used to prepare SF₅-containing polymers, sulfur pentafluorophenyl pyrazoles have been suggested for the control of ecoparasitic infections, and sulfurpentafluoride derivatives have been used to prepare liquid-crystal media. Thus, there is an interest in efficient methods for the introduction of the SF₅ group into a variety of compounds.

[0003] The following articles and patents are representative of methods for introducing SF₅ groups into organic compounds.

[0004] US 4,535,011 discloses a process for producing mono (pentafluorosulfur diacetylene polymers wherein sulfur pentafluoro bromide is first reacted with acetylene at temperatures below about -70 °C, and then, the resulting intermediate debrominated. Dehydrobromination is effected by reacting the intermediate adduct with a strong base, e.g., potassium hydroxide.

[0005] US 6,479,645 discloses methods for producing sulfurpentafluoride compounds having a substituted silyl group. In the disclosed process, sulfur pentafluoro bromide is reacted with a trisubstituted silyl acetylene in the presence of potassium fluoride at room

temperature. Bromine is removed from the intermediate compound by addition of powdered potassium hydroxide.

[0006] The article, *New and Convenient Method for Incorporation of*

Pentafluorosulfanyl (SF_5) Substituents Into Aliphatic Organic Compounds, Samai Ayt-

5 Mohand and W. Dolbier, *Organic Letters*, 2002, 4, 17, 3013 discloses the addition of the SF_5 -group to organic compounds by the reaction of SF_5Cl with alkynes and alkenes in the presence of triethylborane and hexane solvent at temperatures from $-30\text{ }^\circ\text{C}$ to room temperature.

[0007] In the article, *New SF_5 -Long Chain Carbon Systems*, R. Winter and G. L. Gard,

10 *Inorganic Chemistry*, *Journal of Fluorine Chemistry*, 107 (2001) 23-30, sulfur pentafluoro chloride is reacted with a terminal olefin, e.g., 1-hexene and 9-decyl-1-acetate to produce an intermediate in the formation of SF_5 -terminated perfluoroalkyl thiols. The authors note that the reaction of sulfur pentafluoro bromine is too reactive with 1-hexene and only BrF adducts are found by GC analysis.

[0008] In the article, *The $-\text{SF}_5$, SeF_5 , and TeF_5 Groups In Organic Chemistry*, D. Lentz and K. Seppelt, *Chemistry of Hypervalent compounds* © 1999 Wiley-VCH, Inc, p. 295-325, there is disclosed the addition of the SF_5 group into organic compounds by reaction with S_2F_{10} , SF_5OF , SF_5Cl , and SF_5Br . Successful addition of SF_5Br to alkynes and fluoroalkenes was reported. It was reported also that SF_5Br added in cases where SF_5Cl

20 failed and SF_5Cl added in cases where SF_5Br did not.

[0009] The article, *Functionalization of Pentafluoro- λ^6 -Sulfanyl (SF_5) Olefins and Acetylenes*, Winter and Gard, et al, American Chemical Society, ©1994 128-147

discloses the preparation of SF_5 derivatives of alkynes and alkenes. In one example SF_5X addition to alkenes can be moderated by working either in the gas phase, (ethylene and SF_5Br), operating at low temperatures ($-110\text{ }^\circ\text{C}$) or the reaction carried out at high

25 dilution in an inert solvent.

BRIEF SUMMARY OF THE INVENTION

[0010] It has been discovered that one can improve the addition of the SF_5 group to

30 organic compounds such as alkyl-substituted terminal alkenes, and effect addition of the SF_5 group to internal alkenes and cycloalkenes via reaction with SF_5Br . The improvement in the addition process for reaction with a terminal olefin comprises

condensing SF₅Br in the terminal olefin and effecting the reaction of SF₅Br with under liquid phase conditions. For terminal, internal, and cyclic olefins, SF₅Br is condensed in the olefin and the reaction carried out under liquid phase conditions in the presence of a free radical initiator, preferably triethyl borane. In addition, the invention relates to

5 compositions incorporating the SF₅ group and Br group across the double bond of an internal or cyclic olefin. Processes for producing the resulting compositions have been, heretofore, unknown. The resulting pentafluorosulfuranyl halo substituted aliphatics can be converted to pentafluorosulfuranyl substituted aliphatics by effecting dehydrohalogenation or dehalogenation.

10 **[0011]** Generally, several advantages can be achieved by this process and these include:

an ability to incorporate the SF₅ group into terminal alkenes in improved yield, particularly those which do not have substituent electron withdrawing groups, in high yield; and,

15 an ability to reduce byproduct formation due to BrF addition across the double bond and loss of reactant SF₅Br.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Addition of an SF₅ group to an olefin allows for the production of many

20 intermediates which are useful in organic synthesis. Heretofore, successful addition of the SF₅ group to terminal alkenes by reaction with SF₅Br has been limited to those alkenes bearing electron withdrawing groups such as F, Cl, Br, SiR₃ and COOEt. Reaction of SF₅Br with unsubstituted terminal alkenes has largely resulted in the addition of F and Br across the double bond either instead of, or in addition to, the desired

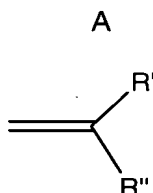
25 addition of the SF₅ group and the Br group across the double bond. Reaction of SF₅Br with internal olefins has either met with F and Br adding across the double bond or there has been no reaction.

[0013] The improved processes for reaction with an olefin described herein employs the reactant, SF₅Br as the means for effecting the addition of the SF₅ group to such

30 olefinic compounds and particularly those olefinic compounds heretofore not amenable to addition of the SF₅ group and Br across the double bond. In a first embodiment of the improved process, the reaction is carried out under liquid phase conditions and, as a

second embodiment the reaction of SF_5Br with the olefin is carried out in the presence of a free radical initiator, preferably triethyl borane.

[0014] The olefins suited for reaction with SF_5Br include terminal alkenes, internal olefins and cycloalkenes. Representative terminal olefins are represented by the structure:

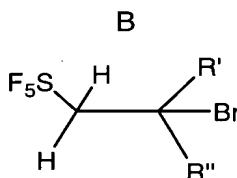


wherein R' and R'' are separately H, C_{1-20} , preferably C_{3-12} alkyl or substituted alkyl, aryl or alkyl substituted aryl, C_{1-10} alkoxy, C_{1-10} alkyl ether, or alkenyl.

Representative substituents on or within the alkyl group include heteroatoms such as O, S, N or halogen atoms such as Cl, Br, and F. Other specific groups include OCH_3 , $-\text{CH}_2\text{OCH}_2-$, SCH_3 , $-\text{CH}_2\text{S}-\text{CH}_2-$, $\text{N}(\text{CH}_3)_2$, $-\text{CH}_2\text{N}(\text{CH}_3)\text{CH}_2-$, CH_2Cl , $-\text{CH}_2\text{CH}_2\text{Cl}$, etc.

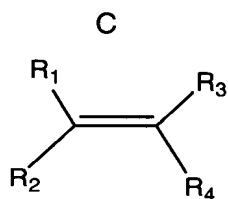
Specific terminal olefins such as C_3 to C_{12} alkenes, e.g., propylene, isobutylene, pentene, hexene, heptene, octene, decene, and dodecene, cyclic olefins such as 4-vinyl-1-cyclohexene, and aryl olefins such as styrene, and divinyl benzene. Nonconjugated dienes such as 1, 4-pentadiene, 1, 4-hexadiene, 1, 5-hexadiene and 1, 4-heptadiene, 1, 5-heptadiene, 1, 6-heptadiene can also be reacted.

[0015] The resulting pentafluorosulfuranyl bromo alkane compounds are represented by the structure:



[0016] Internal aliphatic olefins, have been the most difficult to effect addition of the SF_5 group and Br across the double bond. Too often, no reaction occurs. By that it is meant only Br and F add across the double bond. By operating under liquid phase conditions and facilitating the reaction by the use of a free radical initiator, preferably one that is activated at low temperatures, e.g. below 0°C , one can add SF_5 and Br using

SF₅Br as the reactant. Internal olefins suited for the reaction are represented by the structure:



5

wherein R₁, R₂, R₃, R₄ are C₁₋₁₂ alkyl, preferably C₁₋₈, or substituted alkyl, aryl or substituted aryl, alkoxy, alkyl ether, alkyl ester and nitrile, with R₂ and R₄ additionally being = H or halogen atoms, e.g., F, Cl and Br. Representative substituents on or within the internal olefin can include heteroatoms such as O, S, N or halogens, such as OCH₃, -CH₂OCH₂-, SCH₃, -CH₂S-CH₂-, N(CH₃)₂, -CH₂N(CH₃)CH₂-, -CH₂Cl, -CH₂CH₂Cl, etc.

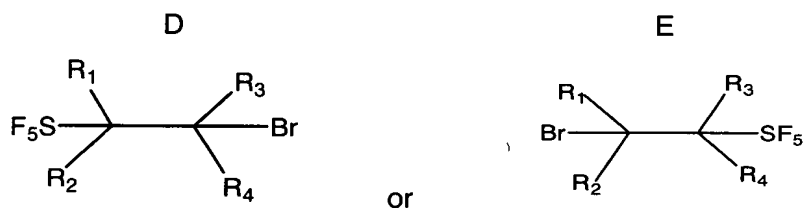
Where isomers of the olefins exist, e.g., in the form of cis and trans,- forms, such olefins can be used as a reactant. Representative compounds include butene, pentene, hexene, heptene, octene, nonene, dodecene and the like where the olefinic bond is internal and not terminal. Substituted examples of internal alkenes include 2-halo-2-

10 butene, 2,3-dihalo-2-butene, 2-alkoxy-2-butene, 2,3-dialkoxy-2-butene, 2-dialkylamino-2-butene, 2,3-(bis)dialkylamino-2-butene, 2-thioalkyl-2-butene, and 2,3-(bis)thioalkyl-2-butene etc.

15

[0017] Compounds resulting from the addition of SF₅Br to an internal olefin are represented by the structures:

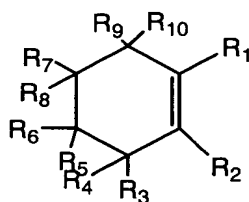
20



[0018] Another category of olefins include the cycloaliphatic olefins represented by the

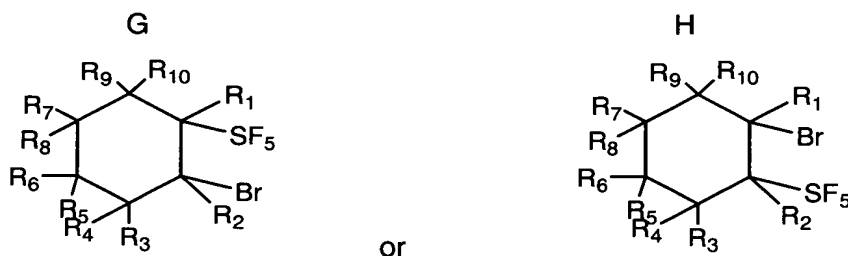
25 formula:

F

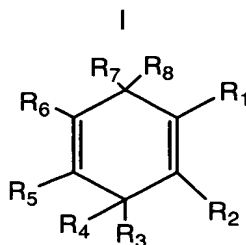


- wherein R_1 - R_{10} = H, halogen atoms, alkyl or substituted alkyl, aryl or substituted aryl. Substituents include heteroatoms such as O, S, N or halogens R_9 , R_{10} or R_3 , R_4 may be a carbonyl group ($=O$); R_9 or R_{10} and R_4 or R_3 may be linked together, i.e., bridged bicyclic compounds; R_7 or R_8 and R_5 or R_6 may be linked together as in. fused ring bicyclic or tricyclic cycloaliphatic or aromatic compounds. Representative cyclic olefins include: cyclohexene, cyclooctene, norbornene, dihydronaphthalene, dihydroanthracene, dihydrophenanthrene, octahydronaphthalene, dodecahydroanthracene, dodecahydrophenanthrene and the like.

[0019] Compounds produced by the reaction of SF_5Br with the above cycloaliphatic olefins are represented by the structures:



[0020] The last class of olefinic compounds are the cycloaliphatic dienes which are represented by the formula:

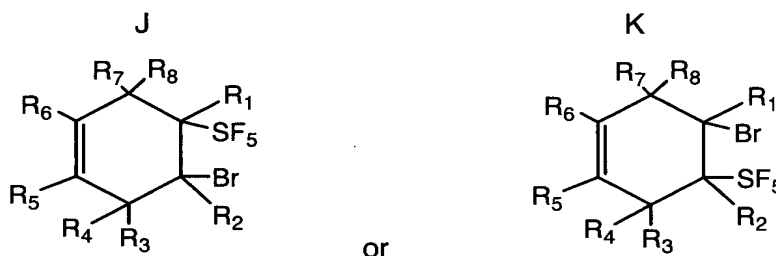


wherein R_1 - R_8 = H, halogen atoms, alkyl or substituted alkyl, aryl or substituted aryl. Substituents include heteroatoms such as O, S, N or halogen atoms, e.g., F, Br, and Cl; R_7 or R_8 and R_4 or R_3 may be linked together, i.e., bridged bicyclic compounds R_7

or R_8 and R_5 or R_6 may be linked together as in. fused ring bicyclic or tricyclic cycloaliphatic. The dienes may be used as long as the olefinic bonds are not conjugated. This also includes the situation where the bonding is carbonyl.

Representative dienes include: 1,4-cyclohexadiene, 1,6-hexahydronaphthalene, 9,13-tetrahydroanthracene and unconjugated dienes in other cycloaliphatic ring of ring size C_5-C_{10} .

[0021] The pentafluorosulfuranyl bromo aliphatic compounds are represented by the structures:



[0022] The reaction stoichiometry involving the reaction of SF_5Br with an olefin is generally consistent with the level of SF_5 addition desired. Typically the reaction stoichiometry employs an equivalent or slight excess of SF_5Br reactant, e.g., from about 1 to 1.2 moles SF_5Br per mole of olefin bond.

[0023] The ability to achieve enhanced addition of the SF_5 group into internal and cyclic olefins without effecting substantial addition of Br and F across the double bond resides in effecting the reaction in the presence of a free radical initiator such as trialkyl boranes, e.g., tripropyl borane, and particularly triethylborane. Other free radical initiators include azo compounds, organic peroxides, e.g. benzoyl peroxide and t-butylhydroperoxide, and UV light. Low temperature initiation is preferred to prevent the formation of polymerization byproducts.

[0024] The free radical initiator, e.g., triethylborane is added in an amount of 1-25 mol%, preferably 5-10 mol %, per mole of the olefin to be treated. Triethyl borane is the preferred initiator in view of its reactivity at low temperatures, e.g., as low as $-78^\circ C$.

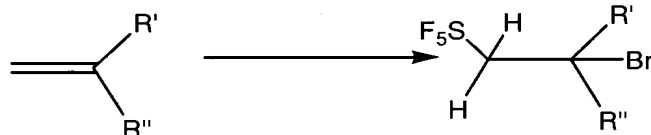
[0025] The reaction can be carried out in a wide range of liquid mediums, i.e., the reaction can be carried out in the presence of olefin neat or it can be carried out in the presence of solvents. Representative solvents suited for carrying out the reaction include hydrocarbons, fluorocarbons, nitriles, ethers, and halocarbons. Solvent levels of from 10 to 100% by weight of the olefin can be used.

[0026] The reaction of SF_5Br with the olefins is carried out at temperatures below the decomposition of SF_5Br , but above the activation temperature for the free radical initiator. The advantage of triethyl borane as a free radical initiator is that it is active at a low temperature, from about -90°C to the boiling point of solvent or olefin, preferably low temperatures from -80 to $+50^\circ\text{C}$, and most preferably from about -75°C to 0°C . In the process, the SF_5Br reactant is condensed into the reaction medium, and then the reaction carried out under liquid phase conditions.

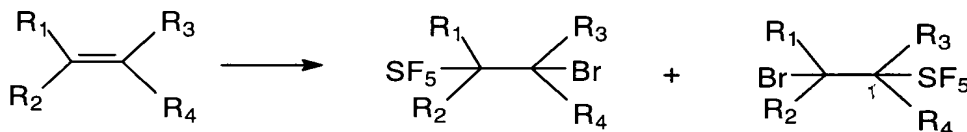
[0027] Recovery of the product can be accomplished by conventional methods and these include distillation and chromatography. An advantage of using SF_5Br to SF_5Cl is that the bromine atom facilitates removal of the halogen atom from the thus formed product. Removal can be effected by addition of a strong base, e.g., potassium hydroxide, HBr being eliminated. Br can also be replaced by H through the use of reducing agents, e.g., tin hydrides. As a result there is an easy mechanism for the production of pentafluorosulfuranyl aliphatics via SF_5Br addition with a variety of olefins.

[0028] The following reactions are representative embodiments of the described process:

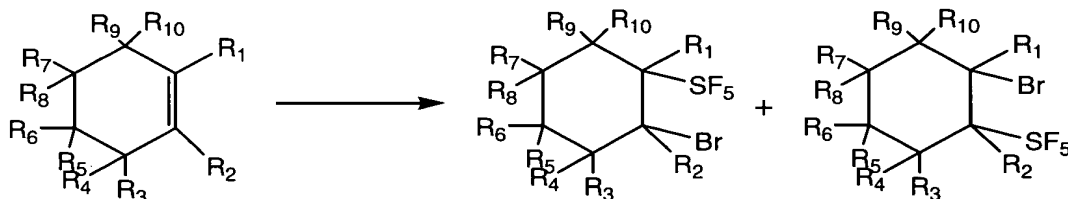
Liquid Phase SF_5Br Addition To Terminal Olefin

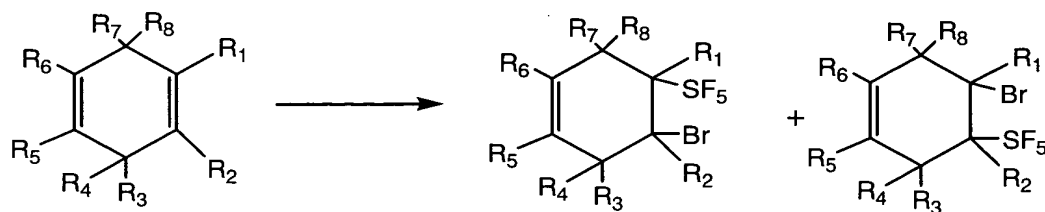


Catalyzed SF_5Br Addition To Internal Olefins And To The Resulting Compositions



Catalyzed SF_5Br Addition To Cycloalkenes



Catalyzed SF₅Br Addition To Cycloalkyldienes

[0029] In the above reaction with cycloalkyldienes, SF₅Br can be added to one or both double bonds depending upon the reaction stoichiometry and conditions.

- 5 **[0030]** The following examples are intended to represent various embodiments of the invention and are not intended to restrict the scope thereof.

General Procedures

A. Uncatalyzed, Liquid Phase SF₅Br Addition to Alkenes

- 10 **[0031]** The alkene (2 mmole), pentane solvent (10mL) and potassium fluoride (5 mmole) were charged to an FEP tube fitted with an inlet valve and a relief valve. The solution was cooled to -78° C and degassed. SF₅Br (2 mmole) was then condensed into the solution. The temperature was maintained at -78° C for one hour, and then, the solution was allowed to warm to room temperature. After 30 minutes the reactor was
15 vented and purged with N₂. The reaction mixture was slowly added to a cold sodium bicarbonate solution. The organic layer was isolated and the products were analyzed by GC, GC/MS and NMR.

B. Catalyzed, Liquid Phase SF₅Br Addition To Alkenes

- 20 **[0032]** The alkene (2 mmole), pentane solvent (10mL), potassium fluoride (5 mmole) and triethylborane (0.2 mmole, 1 M in hexane) were charged to an FEP tube fitted with an inlet valve and a relief valve. The solution was cooled to -78° C and degassed. SF₅Br (2 mmole) was then condensed into the solution. The temperature was maintained at -78° C for one hour, and then, the solution was allowed to warm to room
25 temperature. After 30 minutes the reactor was vented and purged with N₂. The reaction mixture was slowly added to a cold sodium bicarbonate solution. The organic layer was isolated and the products were analyzed by GC, GC/MS and NMR.

Example 1


Reaction Of SF₅Br With Terminal Olefins.

[0033] Terminal olefins were reacted with SF₅Br using procedure A described above.

5 The GC area% results are shown in Table 1.

Table 1.

GC Area % for the Uncatalyzed, Liquid Phase
Reaction of SF₅Br with Terminal Olefins.

	Alkene	Temp (° C)	Catalyst	SF ₅ Br Addition
1	H ₂ C=CH(CH ₂) ₅ CH ₃ 1-Octene	-78	None	79
		-78	Et ₃ B	100
2	H ₂ C=CHCH ₂ OCH ₂  Allylglycidyl ether	-78	None	98
3	H ₂ C=CH(CH ₂) ₂ CH=CH ₂ 1,5 Hexadiene	-35	None	70 12 2-SF ₅

10 [0034] Characterization of the SF₅Br addition products:

[0035] 1. 1-Pentafluorosulfanyl-2-bromo octane MW= 276. GC/MS m/z= 277, 275, 239, 127, 111, 89, 69, 57. ¹H NMR δ 0.9, (t, 3H), 1.3 (m, 6H), 1.4 (m, 1), 1.5 (m, 1H), 1.8 (m, 1H), 2.0 (m, 1H) 4.0 (m, 1H), 4.1 (m, 1H), 4.4 (m, 1H) ¹⁹F NMR δ 65 d, 82 pent.

[0036] 2 1-Pentafluorosulfanyl-2-bromo glycidyl ether MW= 321. GC/MS m/z =
15 249, 247, 141, 139, 127, 113, 89, 87, 57. ¹⁹F NMR δ 65 d, 82 pent.

[0037] 3 1-Pentafluorosulfanyl-2-bromo-5- hexene MW= 289. GC/MS m/z = 290, 288, 208, 206, 161, 163, 127, 122, 120, 89, 81. ¹H NMR δ 1.9, (t, 1H), 2.1 (m, 1H), 2.2 (m, 1), 2.3 (m, 1H), 4.0 (m, 1H), 4.2 (m, 1H) 4.4 (m, 1H), 5.1 (dd, 2H), 5.8 (m, 1H) ¹⁹F NMR δ 65 d, 82 pent.

20 [0038] Double Addition product GC/MS m/z = 496, 418, 417, 289, 287, 181, 179, 127, 119, 99, 89, 59

[0039] The results in Table 1 show that the addition of the SF₅ group to a terminal olefin can be effected by condensing SF₅Br in the olefin and carrying out the reaction in the liquid phase. Yields can be improved in many cases where unsubstituted olefins or where the olefin has more than one double bond by the use of a free radical catalyst, e. g., triethyl borane. This is surprising in view prior art reports that SF₅Br is too reactive and only Br-F adducts are formed when using SF₅Br as a reactant. The prior art suggested the reactions, if they were to proceed, must be carried out either at gas phase conditions, at low temperatures (−110 °C) or at high dilution in an inert solvent. Where functional groups are present, e.g., a glycidyl ether, greater yields can be produced.

However, as the results show in the case of reaction with hexadiene, SF₅ adds to the first double bond but SF₅ addition is dramatically reduced once addition to the terminal olefinic bond has been accomplished. Yield of SF₅ can be increased across both of the double bonds by the use of a low temperature free radical initiator.

Example 2

Catalyzed And Uncatalyzed, Liquid Phase Reaction Of Internal Olefins With SF₅Br

[0040] Internal olefins were reacted with SF₅Br using either procedure A and B described above. The GC area% results are shown in Table 2.

Table 2.
GC Area % for the Reaction of SF₅Br with Internal Olefins.

	Alkene	Temp (° C)	Catalyst	SF ₅ Br Addition
4	CH ₃ CH ₂ CH=CH(CH ₂) ₂ CH ₃ Cis 3-Heptene	-78	Et ₃ B	86
		-78	None	0
5	CH ₃ CH ₂ CH=CH(CH ₂) ₂ CH ₃ Trans 3-Heptene	-78	Et ₃ B	73
		-78	None	50
6	CH ₃ (CH ₂) ₂ CH=CH(CH ₂) ₂ CH ₃ Trans 4-Octene	-78	Et ₃ B	91
		-78	None	0

Characterization of the SF₅Br addition products:


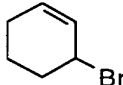
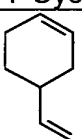
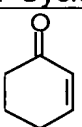
- [0041] 4 3-Pentafluorosulfanyl-4-bromo heptane and 3-bromo-4-pentafluorosulfanyl heptane Mw= 305. GC/MS m/z= 177, 175, 137, 135, 127, 97, 89, 69,55. ¹⁹F NMR δ 60 t, 86 pent.
- 5 [0042] 5 3-Pentafluorosulfanyl-4-bromo heptane and 3-bromo-4-pentafluorosulfanyl heptane Mw= 305. GC/MS m/z= 177, 175, 137, 135, 127, 97, 89, 69,55. ¹⁹F NMR δ 58 t, 60 t, 86 pent.
- [0043] 6 4-Pentafluorosulfanyl-5-bromo octane, Mw= 319. GC/MS m/z= 193, 191, 127, 111, 89, 69,55.
- 10 [0044] The results in Table 2 show that unlike the terminal olefins in Example 1, the uncatalyzed, liquid phase reaction of SF₅Br with an olefin, where the olefinic bond is internal, is either ineffective in many cases or yields are low, e.g., 50%, depending upon the isomer structure. When a free radical initiator is used to catalyze the liquid phase reaction, e.g., triethyl borane, addition of the SF₅ group can be, yields are increased
- 15 dramatically. Byproduct formation, i.e., products where there is BrF addition across the double bond are minimized.

Example 3

Catalyzed and Uncatalyzed Reaction of SF₅Br With Cycloalkenes.

- 20 [0045] Cycloalkenes were reacted with SF₅Br using procedures A and B described above. The GC area% results are shown in Table 3.

Table 3.
GC Area % for the Reaction of SF₅Br with Cycloalkenes.

	Alkene	Temp (° C)	Catalyst	SF ₅ Br Addition
7	 Cyclohexene	-78	Et ₃ B	91
		-78	None	48
8	 3-Bromo-1-Cyclohexene	-78	Et ₃ B	50
		-78	None	5
9	 4-Vinyl-1-Cyclohexene	-78	Et ₃ B	34 1-SF ₅ + 55 2-SF ₅
		-78	None	56
10	 2-Cyclohexen-1-one	-78 *	Et ₃ B	34
		-78 *	None	0

* Reaction did not go to completion.

5 Characterization of the SF₅Br addition products:

[0046] 7 1-Pentafluorosulfanyl-2-bromo cyclohexane Mw= 289. GC/MS m/z= 290, 288, 209, 127, 101, 89, 81. ¹H NMR δ 1.3, (m, 2H), 1.6 (m, 2H), 1.8 (m, 1H), 2.1 (m, 1H), 2.2 (m, 2H), 2.4 (m, 1H) 4.3 (m, 1H), 4.9 (d, 1H) ¹⁹F NMR δ 57 d, 85 pent.

[0047] 8 1-Pentafluorosulfanyl-2, 3-dibromo cyclohexane Mw=368 GC/MS m/z= 368, 288, 207, 181, 179, 161, 159, 127, 99, 89, 79.

[0048] 9 Mw= 316 GC/MS m/z= 316, 314, 235, 189, 187, 127, 107, 89, 79.

[0049] Double addition product Mw= 523. GC/MS m/z= 315, 313, 253, 207, 205, 187, 185, 145, 127, 105, 79.

[0050] 10 3-Pentafluorosulfanyl-2-bromo cyclohexanone Mw=303. GC/MS m/z= 302, 300, 177, 175, 149, 147, 127, 121, 119, 89, 67.

[0051] The results in Table 3 show that, at best, the uncatalyzed liquid phase reaction of cycloalkenes results in a poor yield of SF₅ addition product. The yield of SF₅ products is increased by the addition of a radical initiator. Where there is a substituent on the



cycloaliphatic ring, e.g., a halogen such as Br or a carbonyl group a free radical catalyst is necessary to achieve reaction in a significant amount.

Example 4

5 Catalyzed and Uncatalyzed Reaction of SF₅Br With Cycloalkadienes.

[0052] Cycloalkadienes were reacted with SF₅Br using procedures A and B described above. The GC area% results are shown in Table 4.

Table 4.
GC Area % for the Reaction of SF₅Br with Cycloalkadienes.

	Alkene	Temp (° C)	Catalyst	SF ₅ Br Addition
11	 1,3 Cyclohexadiene	-78	Et ₃ B	-
12	 1,4 Cyclohexadiene	-78	Et ₃ B	97
		-78 **	Et ₃ B	28 1-SF ₅ + 43 2- SF ₅
		-78	None	36

10 ** two equivalents SF₅Br added to the reaction.

Characterization of the SF₅Br addition products:

[0053] 12 1-Pentafluorosulfanyl-2-bromo- 4-cyclohexene Mw= 287. GC/MS m/z= 288, 286, 207, 161, 159, 127, 99, 89, 79. ¹H NMR δ 2.6, (d, 1H), 3.0 (dt, 3H), 4.4 (m, 1H), 5.0 (m, 1H), 5.7 (m, 2H) ¹⁹F NMR δ 55 d, 84 pent.

15 **[0054]** The results in Table 4 show the position of the double bond is important. When the double bond is not conjugated, high yields of SF₅ addition can be achieved when a free radical initiator is employed. If the bonds are conjugated, yields of SF₅ are low even when a free radical initiator is employed.

20

Example 5

Catalyzed and Uncatalyzed Reaction of SF₅Br With Norbornene

[0055] Norbornene was reacted with SF₅Br using procedures A and B described above. The GC area% results are shown in Table 5.

Table 5.
GC Area % for the Reaction of SF₅Br with Norbornene.

	Alkene	Temp (° C)	Catalyst	SF ₅ Br Addition
13	Norbornene	-78	Et ₃ B	98
		-78	None	-

Characterization of the SF₅ containing products:

- 5 **[0056]** 13 1-Pentafluorosulfanyl-2-bromo norbornane Mw=301. GC/MS m/z= 223, 221, 175, 173, 127, 113, 93, 89, 67.

[0057] The results in Table 5 show bicyclic molecules containing a double bond show high yields of SF₅ addition when a radical catalyst is employed in the reaction with SF₅Br.

- 10 **[0058]** Summarizing the examples, it can be seen that reaction of SF₅Br with terminal olefins can provide reasonably good yields when the reaction is carried under liquid phase conditions and SF₅Br is condensed into the reaction medium. Low temperature conditions facilitates the condensation reaction. When the reaction is carried out in the presence of a free radical initiator, yields are increased, particularly in those cases where the terminal olefin is unsubstituted.

- 15 **[0059]** Heretofore, there have been no reports of the successful addition of SF₅ groups to Internal and cyclic olefins by reaction with SF₅Br. Even when the reaction is carried out under liquid phase conditions and the SF₅Br is condensed into the olefin, very poor to moderate yields of SF₅Br addition are achieved. And, isomer structure is a factor as to whether the reaction proceeds. The results in Tables 2 and 3 also show that the addition
20 of a free radical initiator to the reaction medium in an amount preferably from 5 to 10 mole % significantly enhances the yield of products containing SF₅ group.

[0060] Dienes can be reacted with SF₅Br by employing a free radical initiator. To achieve more than one SF₅ group onto the diene, it is necessary to use a free radical initiator.

- 25 **[0061]** Although not intending to be bound by theory, it has generally been viewed that SF₅Br is too reactive with olefinic molecules resulting in Br-F addition. It is surprising that the addition of a radical catalyst enhances the selectivity for SF₅ addition instead of the customary BrF addition. The mechanism for SF₅Br reactions is by and large believed to be free radical in nature. Some experiments, however, suggest SF₅Br reacts through an

- electrophilic mechanism which results in Br-F addition as the major product. By adding the radical initiator it is believed that we are shifting the mechanism toward the radical pathway as opposed to electrophilic addition, thereby resulting in increased SF₅ addition. Surprisingly, then, by carrying out the reaction, liquid phase, in the presence of a free
- 5 radical initiator, one changes the reaction mechanism such that SF₅ and Br add across the double bond rather than F and Br adding across the double bond.